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Hybrid-XLP: An Efficient Hybrid Cross-Layer Communication Protocol for Ultra Wide Band Wireless Multimedia Sensor Networks

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ABSTRACT

Wireless Multimedia Sensor Networks will be a critical component in Critical Wireless Networks, which is protecting and counteracting a few emergencies and threats and enhance infrastructure for strategic military operations. For enabling these applications, the Wireless Multimedia Sensor Networks need various mechanisms to deliver multimedia content with Quality of Service (QoS). This QoS is one of the most important parameters which should be focussed in Wireless Sensor Networks, which is used to improve the Bandwidth Utilization and Throughput as well.Energy Conservation is another prime parameter which should be considered when designing of Communication protocols for Wireless Sensor Networks (WSNs). The Cross Layer Wireless Multimedia Sensor Networks (XL-WMSN) was proposed recently to facilitate Energy Conservation. This proposed model is achieving very high data rate in Multimedia communication over Wireless Sensor Networks. This is supporting deadline-aware content delivery and also it is focusing Energy Aware Computation. However, from our experimental results, we understood that this XL-WMSN fails to achieve Throughput, Delay and Jitter and also it doesn't provide on demand QoS to users, which is not focusing Bandwidth Utilization too. To address these major issues, this paper has proposed an Efficient Hybrid Cross-Layer Protocol (Hybrid-XLP),which is the combination of XL-WMSN and QoS Routing. From the Simulation Results, it is established that the proposed technique improves the performance of Wireless Multimedia Sensor Networks in terms of Bandwidth Utilization, Throughput, Delay and Interference-Aware Routing. It is also achieving Energy Conservation.

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INTRODUCTION

The Current Paradigm Shift in Wireless Real-Time Multimedia Communication is motivating researchers to develop new concepts and designs. This tremendous growth of Multimedia Communications has encouraged innovations in the field of Wireless Sensor Networks to design Wireless Multimedia Sensor Networks.

There are various applications which are benefiting by the Wireless Multimedia Sensor Networks (WMSNs). Ie these Networks are the utmost suitable for surveillance and monitoring various applications for Health Care , Military, Disaster Relief, Agriculture and etc. As we are facing great security and terrorism threats, researchers have been focusing to design efficient models for these applications. However, the available volume of information attained in these applications has presented a great challenge. Surveillance applications as it is heterogeneous traffic flows, they are demand Latency-Aware Protocol which is incorporating service differentiation to achieve end-to-end deadlines. Further, the MAC, the Media Access Control Protocol could offer prioritized medium access according to the type of traffic. This is an important demand in a few applications of surveillance.

The Multimedia Networks need QoS for guaranteeing a status of parameters like minimizing distortion and jitter, delivery of data within deadline, high throughput and reliability. But however, meeting the end-to-end delay deadline is one of the challenging parameters in Multimedia Communications and hence researchers are focusing these parameters in delay-constrained Multimedia Communications. At the Network Layer, the End-to-End delay could be minimized by choosing a shortest path.

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1. Related Works:

From the available literature survey, it is revealed that there are increasing demands towards cross-layer schemes that are focusing to achieve delay-constrained delivery along with energy minimization in Multimedia Communication. Numerous cross-layer schemes were recently proposed for Wireless Multimedia Sensor Networks and detailed survey has been discussed in a few works (Hamid, Z., 2012; Johannes, K., 2010; Zara Hamid and Faisal Bashir, 2013).

Similarly a few routing protocols have been proposed (Hamid, Z., 2012; Johannes, K., 2010) which are focusing on minimizing latency. These protocols have been focusing QoS parameters such as Propagation Delay, Queuing Delay, Bandwidth Availability, Protocol Processing Time and Shortest Path. A few routing protocols have been proposed to address delay deadlines of packets by providing provide service differentiation and end-to-end delay guarantees as well (Hamid, Z., 2012; Johannes, K., 2010; Tong, F., 2011; Saxena, N., 2008). Authors in (Hamid, Z., 2012; Johannes, K., 2010) were calculating the velocity based on the requirement according to the delay of every forwarding Sensor Node. It is choosing the most energy-efficient neighbour which is meeting the velocity requirement. Authors in (Hamid, Z., 2012; Johannes, K., 2010; Tommaso Melodia, 2010) have provided the differentiated service according to traffic flows. This protocol is trying you to get guarantees energy-efficient paths which are meeting the end-to-end delay requirements.

The prioritized scheduling scheme developed to minimize the Delay at MAC layer which is giving priority to a few applications which are delay intolerant one. The RAP (Hamid, Z., 2012; Johannes, K., 2010; Zara Hamid and Faisal Bashir, 2013) is a another type of Communication Architecture for Wireless Sensor Networks which was proposing velocity- monotonic scheduling to minimize the packets deadline miss ratios. Every packet is assigning different deadline based on the requirement. This was ensuring prioritization in the MAC layer. This type of Layered Models (Hamid, Z., 2012; Johannes, K., 2010; Saxena, N., 2008; Shah, G.A., 2010; Tong, F., 2011; Tommaso Melodia, 2010) have been proposed to offer different solutions for MAC, Rate Control and Routing. Wireless Multimedia Sensor Networks have inter-dependence between the different Protocol Stack Layers. To address Energy Aware Admission Control, Authors Zara Hamid and Faisal Bashir have proposed XL-WMSN, which was a Cross-Layer Protocol which is integrating an Energy-Aware Admission Control jointly with traffic-aware routing protocol.

However, the Modular Cross-Layer Controller is required which will improve the performance of existing XL-WMSN in terms of Energy-Aware Admission Control, Bandwidth Utilization, Load Balancing and also it is supporting users to achieve QoS requirements.

2. Cross Layerprotocol for WMSNs XL-WMSN:

The working principle of XL-WMSN (Johannes, K., 2010) is a combined Cross-Layering Model between MAC Layer and the Network and hence both the layers have exchanging their information effectively to achieve delay deadlines. The different functionalities of these layers of Cross-Layer model is discussed at the below the Network Model section.

2.1 Network Model:

This research work have discussed and presented the functions of XL-WMSN. The Sensor Network has represented in graph asG(V,E), where $V = \{vi , ... , v_N \}$ is the Nodes' finite set with $N = |V|$ and E is the Nodes Links. That is all the nodes are within the range of transmission. For example, sensor nodes v_i and v_j are within each other and $e_{ij} \in E$. The Network based on this constraint is fully connected with each other ready for Communication. Nodes are forwarding their data to sink based on the methodology of many-to-one Routing Paradigm. Here, Every Node has performing the duty cycle operation which distributed one so that Node is switched on or switched off for a required period based on the schedule. Here, this work is assumed that Sink is always in ON State. The on-off schedules ie periods can be managed with the help of a duty cycle parameter, δ, it is defining the fraction of the time while node is activated.

CSMA-based methodology is employed for the shared channel access. In this CSMA-based Technology, the each nodes carrier sensing range is represented by d_s, where $d_s \geq d_{c.}$ As it is considered as Error-Free channel, node always receiving packets successfully without dropping them. Each Sensor Node on Networks is receiving and transmitting packets in a multi-hop fashion. MAC Layer storing packets at the incoming Queue and all the packets have been queued.

Wireless Multimedia Sensor Networks are event-based Networks with heterogeneous flows. Each traffic flow such as video traffic has various end-to-end delay requirements and mostly the video traffic need very strict latency requirements.

2.2 Energy-Aware Admission Control:

The Energy-Aware Admission Control is a significant scheme which is used for providing Quality of Service (QoS)Network. It is ensuring that the new connection is permitted to establish when there are sufficient resources available. There are different Admission Control Schemes have been proposed to handle ensure QoS through Admission Control. A few QoS Parameters are Feasibility or Resource Utilization and Energy Consumption (Hamid, Z., 2012; Johannes, K., 2010; Zara Hamid and Faisal Bashir, 2013). It measures the available bandwidth and then if the bandwidth is sufficient then new connection is establishing. The Proportional Distribution Admission Control. Scheme is allowing a mobile node to establish or discard a flow. In (Hamid, Z., 2012; Johannes, K., 2010; Zara Hamid and Faisal Bashir, 2013), the proposed Admission Control Scheme is treating the various packets differently based on the constraints of delay and reliability.

XL-Wireless Multimedia Sensor Network is aiming to provide QoS guarantees as well as it is focusing to minimize energy usage or consumption. To achieve this goal, this scheme is taking into consideration the available energy on a node. And also it is helping router to avoid Nodes which are having less energy to make route and hence the battery drainage is avoiding. This is a great idea to avoid Network holes. When a source node is sending data, it is broadcasting a route request which is referred as (RREQ) packet to its all neighbours. Every Node which is receiving the RREQ is determining whether it needs to participate based on the P value, which can be calculated as follows.

$$P = \begin{cases} 1 & \mathrm{E_{Rem}} > E_T \\ 0 & \text{otherwise} \end{cases} \qquad (1)$$

If P is 1, then available energy of node E_{Rem} is larger than that of $E_{T,}$ the sink is receiving the RREQ and sending RREP signal and when it is happening, the partial route in the RREQ is becoming full path. If P is 0, then RREQ will be discarded.

2.3 Delay-Aware Routing:

Finding and selecting the best path is the major designing challenge of Routing Techniques. In Wireless Multimedia Sensor Networks, we need to focus to achieve low latency, high through put and jitter. And too need to focus to achieve low path setup time. Thus, the XL-WMSN is using the average Packet Service Time PST_{avg}, Channel Utilization $Util_i$ and hop count for taking its routing decision. The PST providing information of node load when the channel utilization is heavy. The path length can be restricted by the Hop count.

2.3.1 Packet service time:

The following various factors are identified to contribute the delay of all the packets.

- ***Queuing Delay:*** This the time difference between the incoming and outgoing packetrates. If the Queuing Delay is larger one then we could understand that the route is heavily congested, which is reducing the Throughput.
- **Transmission Delay**: It is depending upon the available Bandwidth and packet size.
- **MAC Layer Delay**: This can be calculated by taking into account of all delays like channel sensing and channel reservation.
- **Network Layer Delay**: This is a processing delay which is happened due to finding and selecting routes of packet to all lower layers.

The PST is expressed as

$$T_{PST} = T_{Net} + T_{Queue} + T_{MAC} + T_{Transmit} \qquad (2)$$

where $T_{NET,}T_{Queue,}$ T_{MAC} and $T_{Transmit}$ are the Network Processing Delay, Queuing Delay, MAC Layer Delay and Transmission Delay respectively.

The packet service time (average) PST_{AVG} is estimating though weighted moving average, which is given below in Algorithm *PST.* In this PST Algorithm, the β ($0 \le \beta \le 1$) is the constant value PST_{AVG} as compared with the previous one. In this algorithm, if we are assigning higher weight to β, it is meaning that it is getting more preference to PST_{AVG}. Thus, in dynamic Wireless Multimedia Sensor Networks, the abrupt burst of data will increase congestion suddenly.

Algorithm : PST

Ensure: PST
initialization : $T_{PST} = 0, i = 0$
for each *packet received in time interval t*
do
T_r *= time packet is received at MAC layer*
T_l *= time last bit of packet is transmitted*
$T_{PST} = T_l - T_r$
$PST_{Total} = PST_{Total} + T_{PST}$
i ++
end
At the end of time interval t

$PST_{avgt} = PST_{Total} / i$
$PST_{avgt} = \beta(PST_{avgt}) + (1 - \beta)(PST_{avgt} - 1)$

2.3.2 Channel utilization:

The mean PST is used to indicate both the delay and congestion of a Node and hence this PST helping to find best routes and particularly in Wireless Sensor Networks. The bandwidth of the communication channel is shared by Nodes or Users and almost each neighbour consuming the bandwidth and consequently it is affecting the channel utilization of neighbouring nodes. Measuring channel utilization is an Energy-Intensive task as it is need that a node wanted to awake and listen the channel periodically. This technique is to focus channel utilization on nodes and it is detecting a busy channel. The authors Hamid and *et.al* (2012) modifiedthe MAC layer like the busy nodes are performing channel utilization periodically.

Algorithm : Channel Utilization [3]

The Author[3] proposed a algorithm as follows.

Ensure: Channel Utilization is performed more often on active nodes
At every T seconds do
At every t seconds
ifchannel is busy then
Increment T_{busy}
else
ift < T then
$t = t + 0.016$
else
$t=T$
end if
end if
$Util_T = T_{busy}/T_{interval}$

$Util_T = \beta(Util_T) + (1 - \beta)(Util_T - 1)$

2.3.3 Path Establishment:

The Cross-Layer–Wireless Multimedia Sensor Network (XL-WMSN) is used a reactive routing approach and when a node has information to send, a path will be established for the same purpose. This Reactive approach is lowering the complexity of the overhead of control messages and hence, it is good for Energy-Constrained Sensor Networks. Nature of operation of this routing protocol is depending upon its own weight. Every Node is calculating its weight based on PST_{AVG} and $Util_i$, as given in the following equation(3).

$$W_i = \alpha(1 - PSTvgi) + \gamma(1 - Util_i) \quad (3)$$

where W_i is the node's own contribution to the total cost of the route, PST_{AVG} represents the average *PST* and *Util*is the channel utilization at time period *i*, whereasα and γ be the coefficients which are varied from 0 to 1, where $\gamma = (1 - \alpha)$.

When an event is occurring, all the source nodes have been broadcasting the RREQ messages that to find which are the delayed destination routes. During path establishment after receiving Multiple PREQ, the Node with highest weight is identified to establish the reverse route. As stated in *Route Discovery* Algorithm, once RREQ is received, every node is checking whether PREQ has already received or not.If Nodes are receivingthe RREQ in the first time, it has to update source node's id, W_{Prev}, $HopCnt_{Prev}$withthe routing table and all the same will be broadcasted to other Nodes. If it is a identical RREQ which is present earlier, it is comparing at the routing table with the weight, W_{Prev}, in the receiving RREQ with the weight, W_T.If the W_{Prev}value which is larger than the Weight and the difference in hop count is less than or equal to n, it will make revere route with the Node. Else, it is dropping the packet. When Nodes are deviating from minimum paths, XL-WMSN is providing power to permit unused Nodes which are having lesser PST, which is facilitating to increase the throughput and reduces congestion also.

Algorithm : Route discovery algorithm
Require: *Route Request Packet (RREQ)*
Ensure: *Minimum Delay Path*
If *Receive first RREQ pkt from source ID* ***then***
Establish reverse route with ID_{Prev}
Replace WN withW_{Prev}*and*
IDN with ID_{Prev}*in the RREQ pkt*

Broadcast the RREQ packet to neighbours
else
if
$(((HopCnt_{Prev} - HopCnt_T) \leq n) \land (W_{Prev} > W_T))$ ***then***
Update reverse route with ID_{Prev}
Drop packet
else
Drop packet
end if
end if

2.4 Adaptive MAC:

Currently more researchers are focussing to develop Energy-Efficient MAC Protocols to achieve high throughput with low latency. To save energy, we could periodically putting WSN Nodes into *sleep mode*, which is the recognized best approach in WSNs (Melodia, T., I.F. Akyilidz, 2010). To address this demand, various sleep/wake schemes have been proposed recently. It is noted that the predefined duty cycle schemes were wasting high-energy wastage due to various reasons such as low throughput, high latency and idle listening (Melodia, T., I.F. Akyilidz, 2010). Hence, it is predicted that all the available static duty cycle schemes are not suitable for WMSNs as it is need high throughput and low latency without compromising performance. All the Adaptive schemes employed various metrics like traffic load, traffic priority, network topology, Sensor density and residual energy to regulate duty cycle on nodes. Most of the duty cycle schemes are aiming to preserve the energy, which maximize the network lifetime of Wireless Sensor Networks

2.4.1 Traffic Classification and Queuing Model:

The Network Traffic can be classified as three types namely Class 0, Class 1 and Class 2as follows.

- **Class 0:**This is a one created Traffic Class which is representing the delay intolerant traffic. It is defined to have strict end-to-end delay deadlines.
- **Class 1:** This class is demonstrating delay-tolerant traffic which is relaxing the deadline of end-to-end communication. This Traffic Class can be used for PIR Data, Image and Acoustic.
- **Class 2:**This class is defined for broadcast and route update or synchronization traffic.

In this Model, Class 0 traffic has defined and highest priority is assigned in Cross Layer- Wireless Multimedia Sensor Networks (XL-WMSN). Class1traffic with less strict delay as compared with Class 0 and Class 2 traffics. Packets from every traffic type are buffered in different queues which are shown in the Figure 1.

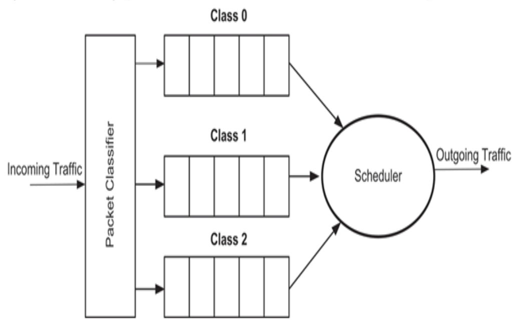

Fig. 1: Queuing Model for QoS based Communication.

When a packet, in a lower priority queueis spending a certain amount of time, then this model itself is risingits priority to a higher priority queue.

3. Identified Problem:

Though the existing XL-WMSN facilitating Wireless Multimedia Sensor Networks in terms of Energy Aware Admission Control and Rouging along with delay and traffic-aware routing protocol, it couldn't support users required QoS and also this research work from its experimental results,it is established that the existing Wireless Multimedia Sensor Networks need to improve its performance further in terms of Throughput, Communication and Queuing Delay, Energy Consumption, Energy-Aware Admission Control, Bandwidth Utilization and Load Balancing.

4. Proposed Hybrid Cross-Layer Communication Protocol (Hybrid-XLP):

As discussed in the previous section, we have understood that the performance of the recently proposed XL-WMSN of Wireless Multimedia Sensor Networks could be improved in terms of Throughput, Communication and Queuing Delay, Energy Consumption, Energy-Aware Admission Control, Bandwidth Utilization and Load Balancing.

That is to address the above mentioned issues, this research work has proposed an Efficient Hybrid-XLP, which is the integration procedure of QoS Routing and XL-WMSN. That is the procedure of the existing XL-WMSN is modified by introducing QoS Routing Technique.

4.1 Procedure of the proposed Hybrid Cross-Layer Communication Protocol (Hybrid-XLP):

After the Network Boots Up, all Sensor Nodes in the Sensor Network run the Hybrid Cross-Layer Communication Protocol which will themselves register their IDs for getting Authentication and then they will communicate each other as follows.

Procedure (Hybrid-XLP)
Call PST()
Call CU()
Call RDA()
QoSRouting() :
PST() :
Ensure: PST
initialization : $T_{PST} = 0, i = 0$
for each *packet received in time interval t*
do
T_r *= time packet is received at MAC layer*
T_l *= time last bit of packet is transmitted*
$T_{PST} = T_l - T_r$
$PST_{Total} = PST_{Total} + T_{PST}$
$i{+}{+}$
end
At the end of time interval t
$PST_{avgt} = PST_{Total} / i$
$PST_{avgt} = \beta(PST_{avgt}) + (1 - \beta)(PST_{avgt} - 1)$
CU() :
Ensure: *Channel Utilization is performed more often on active nodes*
At every T seconds ***do***
At every t seconds
if*channel is busy* ***then***
Increment T_{busy}
else
if $t < T$ ***then***
$t = t + 0.016$
else
$t=T$
end if
end if
$Util_T = T_{busy}/T_{interval}$

$Util_T = \beta(Util_T) + (1 - \beta)(Util_T - 1)$

RDA() :
Require: *Route Request Packet (RREQ)*
Ensure: *Minimum Delay Path*
if*Receive first RREQ pkt from source ID* ***then***
Establish reverse route with ID_{Prev}
Replace WN with W_{Prev} *and*
IDN with ID_{Prev} *in the RREQ pkt*
Broadcast the RREQ packet to neighbors
else
if $(((HopCnt_{Prev} - HopCnt_T) \leq n) \wedge (W_{Prev} > W_T))$ ***then***
Update reverse route with ID_{Prev}

Drop packet
else
Drop packet
end if
end if

QoSRouting() :
Ensure: End-to-end delay requirement of each packet
k=1
Measure dominant traffic type at every i seconds
Calculate ηi, according to dominant traffic type
ifηi<1 **then**

Decrease Cycle / Bandwidth Utilization Gradually
$\delta i+1 = \delta i - di\tau i$
if$\delta i+1 < Cmin$**then**
$\delta i+1 = Cmin$
end if
end if
ifηi>1 **then**
if$di > di-1$ **then**

Increase Cycle / Bandwidth Utilization Gradually
$\delta i+1 = \delta i*(k/\tau i)^{di}$
if$\delta i+1 > 1$ **then**
$\delta i+1 = 1$
end if
$k = k + Ival$
else
Decrease cautiously
$\delta i+1 = \delta i\ (1 - di)\tau i$
if$\delta i+1 < Cmin$**then**
$\delta i+1 = Cmin$
end if
end if
end if
ifηi== 1 **then**
$\delta i+1 = \delta i$
end if

5. Experimental Setup And Performance Evaluation:

As shown in the Figure 2, the Simulation Setup (QualNet 5.0R) of our work is created. This model is implemented with QualNet 5.0 Simulator and studied thoroughly.

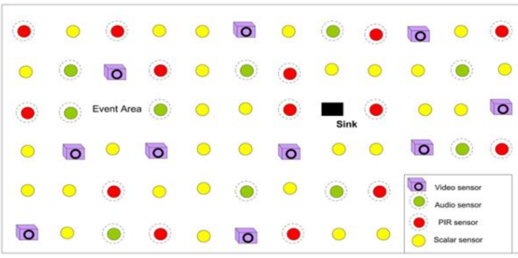

Fig. 2: Simulation Setup (QualNet) of our work.

From the Figure 3 and Figure 4, it is established that our proposed work performs better than that of the existing XL-WMSN in terms of Bandwidth Usage and Fairness. It is also revealed that the proposed model is achieving higher Bandwidth Utilizations as compared with the existing XL-WMSN.

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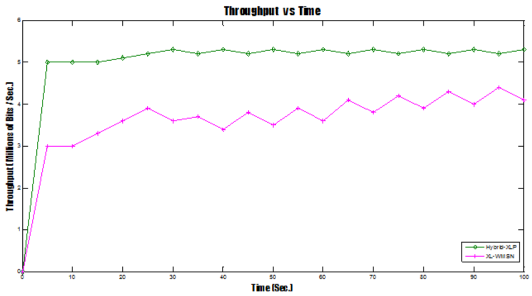

Fig. 3: Throughput.

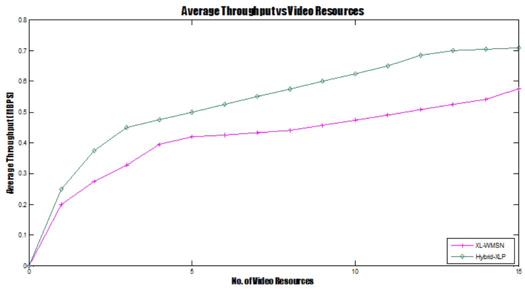

Fig. 4: Average Throughput for Various Video Resources.

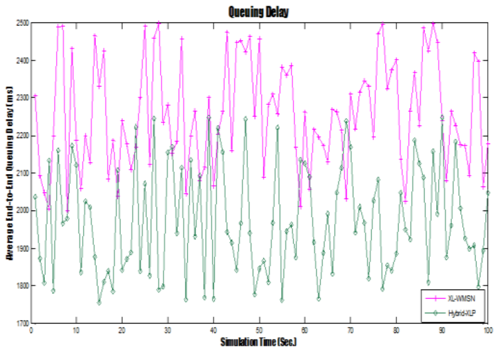

Fig. 5: Average End-to-End Queuing Delay.

The Queuing Delay is the prime parameter in Communication Networks to improve the QoS. From the Figure 5, it is noted that the proposed Hybrid-XLP maintains less Queuing Delay ie Queue Occupancy Time, which is improving Network Performance in terms of Throughput and Communication Delay. It is also facilitate to save power as achieving less packet dropping rate. As the proposed Hybrid-XLP is achieving higher Bandwidth Utilization and less Retransmission to achieve QoS, the Network System consuming less Power Consumption as compared with existing XL-WMSN which is shown in the Figure 6.

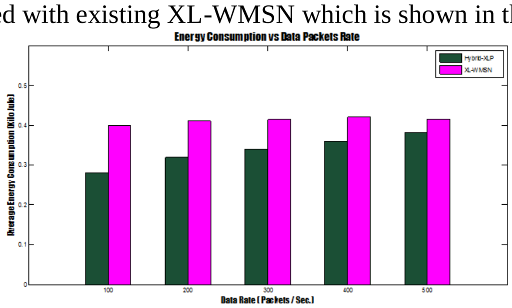

Fig. 6: Energy Consumption.

6. Conclusions:

The Wireless Multimedia Sensor Network (WMSN) is designed as Distributed Systems for communicating Video and Audio Streams, Images and Sensor Data. To achieve these applications, WMSNs need an efficient Protocol. To address the same demand, this research work has designed and implemented an efficient HybridCross-Layer Protocol (Hybrid-XLP). From our experimental Results, it is established that the proposed technique improves the performance of Wireless Multimedia Sensor Networks in terms of Bandwidth Utilization, Throughput, Delay and Interference-Aware Routing. It is also achieving Energy Conservation.

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